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Melting of unfixed material in spherical capsule with non-isothermal wall

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Abstract

Close-contact melting within a spherical capsule is investigated both numerically and analytically. A complete mathematical model is solved numerically by utilizing the boundary fixing method. The approximate approach developed by Bareiss and Beer for the horizontal cylinder is applied to constructing an approximate mathematical model of contact melting in a spherical capsule with a non-isothermal wall. The main characteristic scales and dimensionless parameters which describe the principal features of the melting process are found. Due to the presence of the small parameter in governing equations the perturbation method is implemented. As a result, simple analytical solutions were found which describe close-contact melting inside the capsule with a non-isothermal wall and account for the streamwise convection in the molten layer. The extensive validation of the analytical solution, and its comparison with the numerical results, gives the proof of accuracy of the analytical solutions with estimated error of 10–15%. This conclusion is of crucial importance for evaluating the real latent heat thermal energy storage systems which contain thousands of capsules, since the simple closed-form solutions for a single capsule, used in the mathematical modeling of such kind of complex systems, significantly reduces the cost of numerical computations.

1. Introduction

The analysis of close-contact melting of a solid in cavities is motivated by application in latent heat-of-fusion thermal storage systems. This phenomenon was studied by inclusion of density change during melting of unconfined solids in horizontal cylindrical capsule, numerically by Saitoh and Hirose [1], experimentally by Katayama et al. [2], analytically and experimentally by Bareiss and Beer [3]. Contact melting in a spherical capsule was investigated numerically by Moore and Bayazitoglu [4], Hoshina and Saitoh [5] and later, by applying the technique proposed in [3], Bahrami and Wang [6] and Roy and Sengupta [7] reported analytical solutions. The general scheme for scale analysis of the contact melting problem was proposed by Bejan [8]. Although the aforementioned investigations highlight the main characteristics of contact melting in enclosure, the effect of temperature variation along the wall of the spherical capsule has not been analyzed, and the tangential force convection in the molten layer was neglected. Number of errors and confusing misprints in a recently published paper dealing with contact melting in non-isothermal cylindrical capsule [9] is so excessive that it makes practically impossible neither to use the presented result nor to estimate its correctness. His phrase that 'the time scale of this change is

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